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AUTHOR Collins, Allan
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ABSTRACT

An illustration of the cognitive theory of inquiry teaching is presented in this paper in a tutorial dialogue on the nature of lenses. After a description of the goals of the method, the paper discusses the following ten general strategies inquiry teachers use to accomplish the goals: (1) selecting positive and negative exemplars, (2) varying cases systematically, (3) selecting counterexamples, (4) generating hypothetical cases, (5) forming hypotheses, (6) testing hypotheses, (7) considering alternative predictions, (8) entrapping students, (9) tracing consequences to a contradiction, and (10) questioning authority. The paper then applies the theory to specific materials about the nature of lenses, showing through a detailed presentation of inquiry dialogue how a teacher can pose problems (or cases) to students in a systematic manner to force them to construct and test a theory of domain. It also demonstrates how inquiry teachers start out with an agenda of goals that is continuously updated as the students reveal misconceptions and holes in their knowledge, that in turn generate subgoals for the teacher to correct. (EL)

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CENTER FOR THE STUDY OF READING

Technical Report No. 367

A SAMPLE DIALOGUE BASED
ON A THEORY OF INQUIRY TEACHING

Allan Collins

Bolt Beranek and Newman Inc.

January 1986

University of Illinois
at Urbana-Champaign
51 Gerty Drive
Champaign, Illinois 61820

Bolt Beranek and Newman Inc.
10 Moulton Street
Cambridge, Massachusetts 02238

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Abstract

The paper illustrates the cognitive theory of inquiry teaching by Collins and Stevens (1983) in terms of a tutorial dialogue on the nature of lenses. The dialogue shows how an inquiry teacher poses problems (or cases) to students in a systematic manner to force them to construct and test a theory of the domain. It also shows how inquiry teachers start out with an agenda of goals that is continuously updated as the students reveal misconceptions and holes in their knowledge, that in turn generate subgoals for the teacher to correct.

A Sample Dialogue Based On A Theory Of Inquiry Teaching

By analyzing a variety of teachers who use an inquiry method of teaching (Collins, 1977; Collins & Stevens, 1982), we have formulated a theory of inquiry teaching in terms of the goals, strategies, and control structure different teachers use. In this paper I illustrate the theory by an extended inquiry dialogue on the nature of lenses. Thus, this paper shows how the theory can be applied in detail to one specific context.

Inquiry teachers have two overall goals. One is to teach a deep understanding of a particular domain so that students can make novel predictions about the domain. The other is to teach students to be good scientists, so that they can learn to construct general rules and theories on their own, and be able to test them out. The dialogue tries to encompass both these goals of inquiry teaching. In general, inquiry teachers do not try to teach facts and concepts per se, except insofar as they fit into a general framework or theory of a domain.

The ten general strategies inquiry teachers use to accomplish these goals are shown in Table 1. We describe each of these strategies briefly below:

- 1) Selecting positive and negative exemplars. In selecting cases, teachers often pick paradigm cases where the values of all the relevant factors are consistent with a particular value of a dependent variable. For example,

to illustrate convexity of a lens, a teachers might choose an example where both surfaces curve outward (a positive exemplar) and one where both curve inward (a negative exemplar).

- (2) Varying cases systematically. In selecting cases, teachers often pick a comparison case that varies from the previous case in a systematic way. For example, the teacher might systematically vary the distance between a lens and a piece of paper so the student will see how light rays from the sun (a) cross over, (b) come to a focal point, or (c) fail to come together as the lens moves closer to the paper.
- (3) Selecting counterexamples. If a student forms a hypothesis that is not completely true, the teacher will often select a case that satisfies the student's hypothesis but violates the hypothesized prediction. For example, if a student thinks a magnifying glass always makes letters appear larger, the teacher might hold the glass half way between the letter and the student's eye.
- (4) Generating hypothetical cases. Teachers often generate hypothetical cases in order to force students to reason about situations that are hard to reproduce naturally. For example, if a teacher wants the student to think about what happens to the sun's rays as they go through

a lens held far above a piece of paper, the teacher might ask the student to predict where a hypothetical spot on the sun would appear in the image on the paper.

- (5) Forming hypotheses. Inquiry teachers continually try to make students predict how a dependent variable varies with one or more independent variables or factors. For example, the teacher might ask the student to formulate a hypothesis about what focal length depends on (i.e. curvature of a lens) and how it depends on it (i.e. the more the curvature, the less the focal length).
- (6) Testing hypotheses. Once the student has formulated a hypothesis, the teacher wants the student to figure out how to test the hypothesis. For example, if the student thinks that focal length will be less the more curved the lens, then the teacher might ask how this hypothesis could be tested (e.g. by comparing how high above a piece of paper lenses of different curvature must be held so that the light through them comes to focus).
- (7) Considering alternative predictions. Tutors often encourage students to consider whether a prediction different from the one they have in mind might be correct, in order to foster differential diagnosis as a strategy. For example, if a student thinks that an

image turns upside down as you move a lens toward your eye, the tutor might ask the student to consider whether instead it might turn the image right side up.

- (8) Entrapping students. Inquiry tutors often suggest incorrect hypothesis in order to get students to reveal their underlying misconceptions. For example, a tutor might ask whether as you move a lens closer to a piece of paper, a light shining through it will come more and more into focus (it does not).
- (9) Tracing consequences to a contradiction. Tutors often trace the implications of a student's answer to a contradiction with some other belief the student holds. This forces students to build consistent theories. For example, if the student draws rays of light through a lens bending more when they go to the eye than when they come from the sun, the tutor might ask if the student really thinks the rays will bend more in one case than the other.
- (10) Questioning authority. When students ask what the right answer is, or seem to rely on a text book, inquiry teachers try to get students to conduct their own experiments and reach their own conclusions. For example, if a student asks the teacher whether a lens that is more curved has a shorter focal length, the

teacher might plead ignorance and encourage the student to conduct an experiment to find out.

Insert Table 1 about here.

In running an inquiry dialogue with students, teachers maintain an agenda of goals and subgoals that is continuously updated throughout the dialogue. They start out with very high level goals that spawn subgoals governing the selection of problems and initial questions. But as students answer these initial questions, they reveal misconceptions and holes in their knowledge that in turn generate subgoals for the teacher to diagnose and correct.

The goal of this paper is to apply the theory outlined to teaching specific material about the nature of lenses. The content to be taught is summarized in six basic objectives given us by the editor.

- (1) Students will be able to classify previously unencountered lenses as to whether or not they are convex lenses.
- (2) Students will be able to define focal length.
- (3) Students will explain or predict what effect different convex lenses will have on light rays.

- (4) Students will explain the way in which the curvature of a lens influences both the magnification and the focal length of different lenses.
- (5) Students will be able to state from memory the three significant events in the history of the microscope.
- (6) Students will be able to use a previously unencountered optical microscope properly.

The lesson as written addresses only the first four objectives. I have omitted any teaching of the procedure for using a microscope and the historical facts about lenses that were suggested for inclusion in the lesson. The inquiry method can be very effectively used to teach procedures or history, but in order to do so the procedures and history must be well-motivated. For example, an inquiry dialogue about the procedure for using a microscope might try to get the student to invent the correct procedure by considering all the things that could go wrong at each step in the procedure. To teach history the inquiry teacher would have to know how various events led to other events, so that the teacher can get students to try to predict how history unfolded. However, in the materials submitted to us, neither the procedure nor the history were well-motivated, so without a great deal of work it would have been difficult to develop them into an inquiry dialogue.

The dialogue that follows is derived from interviews with two actual children, but it has been drastically shortened and edited

to emphasize the strategies described above. While only one student is depicted, inquiry teachers often conduct such dialogue with groups of students. If done well, the fostering of multiple hypotheses and argumentation among groups of students can make the method more effective.

The Inquiry Dialogue

1. T. Do you know what the piece of glass in this magnifying glass is called?
2. S. A lens?
3. T. That's right, it's called a lens, like the lens in a camera or the lens in your eye. Why do you think it is curved?
4. S. So you can see things magnified.
5. T. How does it magnify things?
6. S. By bending the light.
7. T. Right, the light bends as it enters and leaves the glass.
Do you know which way it bends?
8. S. No.
9. T. Have you ever held a lens under the sunlight?
10. S. Yes.
11. T. What happened?
12. S. Well, there was a bright spot of light.
13. T. So how must light rays bend as they go through the lens?
14. S. They must bend together to a point.
15. T. Right. Do you know what that point is called?

16. S. No.
17. T. It's the focal point or focus. The light is focused together at that point. Do you know what the shape of the lens in the magnifying glass is called?
18. S. No.
19. T. It's called convex. What do you think the difference is between a convex lens and a concave lens?
20. S. Concave would be inward.
21. T. That's right. Concave lenses curve inward just like caves do, and convex lenses curve outward like a ball or a globe. What would a lens shaped like this be called? (see Figure 1a)
22. S. Concave?
23. T. That's right. Suppose you had a lens shaped like this (see Figure 1b), what would its shape be?
24. S. Convex.
25. T. Right. Suppose you had a lens that was flat on one side and curved on the other like this (see Figure 1c). What kind of lens would that be?

Insert Figure 1 about here.

26. S. A half convex lens?
27. T. It would be a convex lens, and it would bend the light a little differently than a lens that was curved on both

sides. So what happens if you hold a magnifying glass in the sun and bring it slowly down over a piece of paper?

28. S. It makes the paper start burning.
29. T. Yes, with the sun you can make it burn. As you come closer to the paper, what happens?
30. S. Well, the light comes together.
31. T. So as you move the lens closer to the paper, the light comes more and more into focus?
32. S. Yes, I guess so.
33. T. Well let's try it and see what happens. We'll use this flashlight as our sun, and I'll hold it up here. And you move the glass from halfway down toward the paper. What happens?
34. S. The light comes more and more in focus, and then it seems to spread out again.
35. T. So it doesn't keep getting more and more in focus as you go lower.
36. S. No. There is a point about here (holding the lens about half a foot above the paper) where it seems to be most in focus.
37. T. That's right. When the light is in focus on the paper, the distance above the paper is the focal distance or focal length. What do you think the focal length depends on?
38. S. The way the glass curves.

39. T. How do you think it depends on the curvature of the glass?
40. S. When you use a convex lens, the point where it comes to one point would be closer than when it is concave, I think.
41. T. Well suppose I had a concave lens. The light rays might bend together, they might bend apart, or they might go straight through. Which do you think will happen?
42. S. I don't know. Maybe the beams of light would come in and bend apart.
43. T. Right. So you have to have a convex lens to get it to focus together at a single point. Do you still think the focal distance depends on the shape?
44. S. Yeah.
45. T. How?
46. S. Because if it's down low they haven't come together yet. But if it's too far they come together and they cross.
47. T. Right, they cross. And that's why if you get down too low they go out of focus, and if you get too high they go out of focus. What is the point called where they come together?
48. S. The focus point?
49. T. Yes, the focus or focal point. And what is the distance called from the focal point to the lens?
50. S. The focal length.

51. T. Suppose I draw a picture of the sun shining down on my lens, and there was a spot on the sun over on the left side. (see Figure 2a) Now where would that spot be in the image of the sun that falls on the paper?
52. S. I guess on the left side.
53. T. Well let's see. Suppose I draw a picture of the rays coming down through the lens, and bending together to the focal point and falling on the paper. Now where would a sunspot over on the left side of the sun appear on the image of the sun on the paper? (see Figure 2a)
54. S. On the right side.
55. T. Why do you think it would be on the right side?
56. S. Because the beams cross.
57. T. Is the whole image reversed then?
58. S. Yes, all the beams cross over.
59. T. Suppose I lower the lens below the focal point in the picture. Would the sunspot still be on the right side of the image, when it is on the left side of the sun? (see Figure 2b)

Insert Figure 2 about here.

60. S. I don't think so, because the beams haven't crossed over yet.

61. T. Yes, that's right. Now look at this other magnifying glass. What kind of lens does it have?
62. S. It has a convex lens too?
63. T. That's right. Is it as curved as the other one?
64. S. No, it's less curved.
65. T. Okay. Do you think its focal length will be the same as the other one?
66. S. No, it will be different I think.
67. T. Then will it be greater than or less than the other one?
68. S. Well if you hold it in the light, the beams will bend less, so they'll take longer to come together. So I guess its focal length will be greater.
69. T. Perfect. So how would you say focal length is related in general to curvature of the lens?
70. S. Well it must be that the less curved the lens is, the greater the focal length.
71. T. That's right. Do you think that applies to concave lenses as well, or just to convex lenses?
72. S. I don't think concave lenses have a focal length because the light beams never come together.
73. T. If you had a concave mirror would the light rays come together at a point?
74. S. Yes I guess so because they would come in and bounce off the mirror at an angle so they would come together at a point.

75. T. Would that be a focal point?
76. S. Yes I guess so, since they would all come together there.
77. T. That's right. And what would be the focal length?
78. S. I guess the distance from the focal point to the mirror.
79. T. Yes, to the center of the mirror. The focal length of a concave lens is measured in just the same way. So do you think your statement that the less the curvature of the lens, the more the focal length applies to concave lenses as well?
80. S. Let's see. If the glass is curved less, then the beams will come together further out, so I guess it's true for concave lenses too.
81. T. That's absolutely correct. Suppose I hold the magnifying glass over the newspaper, and slowly move it away from the page. What will happen?
82. S. The glass magnifies the image at first, and then it goes out of focus as you raise it up I think. Somewhere the image turns over, because I've seen an upside down image in the magnifying glass.
83. T. Okay, let's try it and see what happens. When you hold the magnifying glass right up against the paper, what happens? (Figure 3 shows the results of the experiment schematically.)

Insert Figure 3 about here.

84. S. It looks just like paper.
85. T. So it doesn't magnify the print when it's right next to it. As you raise it slowly up, what happens?
86. S. The print gets larger until it starts to go out of focus.
87. T. That's right, it magnifies the image more, the further from the paper you raise it. In the other magnifying glass, we saw that the lens wasn't as curved. If you held it up the same distance from the paper, do you think it would magnify the letters more or less or the same amount as this one?
88. S. Well if it's not as curved, I don't think it would magnify the print as much as this one.
89. T. That's right. The magnification is less, the less curved the lens is. Now bring the magnifying glass very slowly up, holding it over the headline. What do you see?
90. S. Okay. I've got an image again and it's upside down.
91. T. As you raise it up is the image getting smaller or larger or staying the same size?
92. S. It's getting smaller. Now it's staying about the same size. When it's right in the middle it doesn't magnify the print much at all.
93. T. Okay. What do you think will happen if you raise it up further toward your eye? Will it get smaller or larger? Will it turn over again?

94. S. I think it will stay upside down and the same size, since the distance from the newspaper is so large that the light rays from it won't change any more.
95. T. That's a really good hypothesis. Let's test it to see if it is correct. Raise the lens slowly from the point of sharpest focus up toward your eye.
96. S. Okay, the image seems to stay the same size. Wow, now it is getting larger and more blurry again. Now it's gone completely out of focus. As it gets near my eye I can see the print again. It's right side up and kind of fuzzy.
97. T. Does it get smaller or larger as you bring it close to your eye?
98. S. It gets smaller, but it never seems to come into focus really.
99. T. Okay. Your hypothesis was a good one, but it didn't turn out to be correct. Can you guess how far up from the page the image flips over?
100. S. Maybe at the focal length. No, that doesn't seem right because that's where the print would be magnified best. Maybe twice the focal length? You must know the right answer. What is it?
101. T. I may think I know the right answer, but I could be wrong. Let's try to measure where it occurs. How can we measure the focal length of this lens?
102. S. We could use a ruler.

103. T. Yes, but what would we measure?
104. S. I guess we should measure the distance from the lens to the paper when the light is focused on the paper.
105. T. That should work. So why don't we do it. I'll hold the light up here and you take the ruler and hold the lens so the focal point is right on the paper. How high is the lens when you do that?
106. S. About 10 1/2 inches from the paper.
107. T. Okay, so that's the focal length. Now what should we measure?
108. S. I guess the distance from the newspaper where you get the best focused image that is magnified, and the distance where the image flips over.
109. T. Okay, what do you measure them to be?
110. S. Well, you get the best magnified image about 2 or 3 inches above the paper and the image goes blurry above that. It must flip over at about the focal length.
111. T. That's right. Where do you think the image flips over as you bring the lens up to your eye?
112. S. It must flip over at one focal length there too.
113. T. Measure it and see.
114. S. Yes it's just about at one focal length it flips over.
115. T. Okay. Let's try to draw a picture of what is happening to the light rays, like we did for the sun shining down through the lens. Suppose we first draw what happens when

the lens is near the print and the eye is way out here somewhere to the right. Now the focal point of the lens will be over here to the left of the printed letter A. Can you draw how the rays going out from the letter A will bend in the lens? (see Figure 4a)

116. S. Well, they'll go out toward the lens and then bend inward toward the eye.
117. T. If the letter is inside the focal length, will the rays bend enough to come together again like you've drawn them?
118. S. I think so.
119. T. In the first picture we drew, with the light rays from the sun, how did the rays come into the lens?
120. S. They came straight in.
121. T. How did they bend?
122. S. They bent together at the focal point.
123. T. So they bent just enough to come together at the focal point. Now in your picture you have the rays going from a point on the A inside the focal length, and then bending in toward the eye.
124. S. That's right. They bend toward the eye, where you see them.
125. T. So then you must think the rays coming from the letter A will bend more than those coming from the sun in the other picture.
126. S. No, the rays should bend the same amount.
127. T. Right. How would you have to change your picture then?

128. S. I guess the rays coming out from the letter would be going straight after they go through the lens. (see Figure 4b)
129. T. Right. If you continue the rays coming out of the lens (by dotting them) back to where the letter is, then you can see how the letter is magnified. Notice they don't come together like the actual rays, so that the letter appears to be the height between the dotted lines and not the actual height.
130. S. Yeah, I see.
131. T. You said earlier that the image would be less magnified for the other lens that is less curved. Can you explain why that is in terms of the picture we just drew?
132. S. Well the rays would bend less as they go through the lens, so the difference between the dotted image and the real letter would be less.
133. T. That's right! Can you also explain why the letters don't appear to be magnified when the lens is right up against the print, in terms of the picture we drew?
134. S. Maybe the rays coming out of the lens don't diverge from the rays coning into the lens as much.
135. T. Why don't you draw a picture and see if that is true.
136. S. What do I draw?
137. T. Well draw the same picture as before, but with the A closer to the lens.

138. S. If I draw the letter right next to the lens then the rays will hit the lens. I guess they will bend less than before.
(see Figure 4c)

139. T. Why would they bend any different than before?

140. S. Will bend the same as before?

141. T. That's right. Now dot in the continuation of the rays going to the eye.

142. S. There is less divergence between the real rays and the imaginary ones. So how much the figure is magnified depends on how close the letter is to the lens. (see Figure 4c)

Insert Figure 4 about here.

143. T. That's perfect. The dotted imaginary rays form what is called a virtual image. It's called virtual, because it's not real. Okay, see if you can draw the picture for the case where the lens is in the middle and there is a reversed image. Treat the rays as if they go in a straight line from the letter to the lens.

144. S. Okay. The rays go straight from the letter to the lens, and then they bend together when they go through the lens. They come together at a point, and cross over. Somewhere after that they reach the eye, so the image looks reversed.
(see Figure 5a)

145. T. That's fine. The image you see when the rays cross over is called the real image. Can you say how the picture is different for the case when the eye is close to the lens?

146. S. Then the eye is up here before the rays reach the point and cross over. So the print looks right side up. (see Figure 5b)

Insert Figure 5 about here.

147. T. Very good. I think you understand now everything I wanted to teach you about the way lenses work.

Commentary on the Inquiry Dialogue

In the comments below I have tried to emphasize how the ten strategies shown in Table 1 are involved in the dialogue, and how goals and subgoals are generated in carrying on the dialogue.

1. In lines 1 to 17 the teacher sets the initial goal of establishing the basic terminology about lenses that they will need for the rest of the dialogue. The teacher tries to find out what the student knows a priori, in order to build on that knowledge. This is preliminary to Objective 2 of the lesson "Defining focal length."
2. In lines 17 to 27 the teacher is still establishing basic terminology, in this case the distinction between convex and concave lenses. The strategy is to present different cases of convex and concave lens and test whether the student can

identify them. This illustrates the strategy in Table 1 of selecting positive and negative exemplars to make the student learn the distinction. This part of the dialogue is aimed at Objective 1, "Classifying lenses as to whether or not they are convex."

3. Lines 27-37 make up the last section of the dialogue directed to the goal of establishing basic terminology. In this case the subgoal is to teach the concept of focal length. First the teacher gets the student to form a hypothesis (Strategy 5 in Table 1) about how the image of the sun will change as the lens is moved closer to the paper (lines 27-32), and then to conduct a mini-experiment (lines 33-37) to test that hypothesis (Strategy 6). One kind of entrapment (Strategy 8) that inquiry teachers use occurs in line 31--there the teacher formulates the student's suggestion into an explicit hypothesis that is incorrect, to which the student accedes in line 32. This whole section also illustrates how the teacher varies cases systematically (Strategy 2). In particular, there are three cases of interest: (1) where the lens is high up and the image is out of focus, (2) where the lens is held at the focal length and the image is in focus, and (3) where the lens is near the paper and the image is out of focus. This section is directly aimed at Objective 2, "Defining focal length."

4. In lines 37-45 the teacher establishes the new goal of forming a hypothesis (or rule) about what factors focal length depends on (Strategy 5). This goal is not fully satisfied until much later (line 80) in the dialogue. In line 40 of this section of the dialogue the student reveals a misconception about how light bends in a concave lens. The teacher pursues the subgoal of correcting this misconception by asking the student in line 41 to consider alternative predictions (Strategy 7) about the bending of light in a concave lens. Once the student understands this correctly, the teacher returns to the original goal in line 43 of determining what focal length depends on. This is in pursuit of Objective 4, "Explaining how curvature of a lens influences focal length."
5. In line 46 the student again leads the conversation away from the teacher's goal, by talking about the rays crossing. The student's answer is a non-sequitur (a common occurrence in dialogues) and yet the teacher picks up on it to review the terminology introduced earlier for focal point and focal length (lines 47-50). This is reviewing for Objective 2.
6. In lines 51-61 the teacher continues the discussion introduced by the student in line 46 about the light beams crossing. Generating a hypothetical case (Strategy 4) of a spot on the sun, the teacher asks the students to hypothesize where that spot would appear in the image of the

sun on the paper. When the student guesses the left side, the teacher chooses as a counterexample (Strategy 3) the cases where the paper is far enough below the lens, that the beams cross over and the image is on the opposite side. In line 59, the teacher systematically varies the case (Strategy 2), so that the spot falls on the other side, and asks the student if it will still be on the right side of the image. This suggestion is another example of how inquiry teachers use entrapment (Strategy 8). This section relates to Objective 3, "Predicting the effects of convex lenses on light rays" and Objective 4, "Explaining how curvature of a lens affects focal length."

7. In lines 61-70, the teacher returns to the prior goal of establishing the relation between the focal length and the curvature of a lens. He does this by introducing another lens with less curvature than the first, thus systematically varying cases (Strategy 2) again. First he reviews whether the student can identify the type of lens in line 61 (Strategy 1). Then in line 65 he asks the student whether it will have the same focal length as the other lens, in order to get the student to form a hypothesis (Strategy 5) about how focal length depends on curvature. The wording of this question is a slight entrapment (Strategy 8). Line 67 again exemplifies the way teachers get students to consider alternative predictions (Strategy 7). In line 70 the

student formulates a quite general rule relating lens shape to focal length. This section is particularly addressed to Objective 3, "Predicting the effects of different convex lenses on light rays," as well as Objective 4.

8. In lines 71 to 80 the teacher pursued the subgoal of determining whether the rule the student had formulated applied to concave as well as convex lenses (Strategy 6). To do this he first had to show the student how to measure focal length of a concave lens by analogy to a concave mirror. This allowed the student (in line 80) to make the generalization of the rule relating focal length to curvature of the lens. This section relates to Objective 4 and completes the overall goal the teacher started pursuing in line 41.
9. In lines 81-92 the teacher starts on a new goal to establish how an image is magnified and where you see an upside-down image versus a right-side-up image. In line 81 he presents the problem to the student of predicting how the image of letters on a page will change as you move a lens through different positions. This again is systematic variation of cases (Strategy 2). After the student makes a hypothesis in line 82 (Strategy 5), the teacher suggests another mini-experiment to test the hypothesis (Strategy 6). In line 87 the teacher asks the student to compare the degree of magnification for two different cases (Strategy 2 again).

This section serves Objective 4, "Explaining how curvature of a lens affects magnification."

10. In line 93 after they have completed half the experiment the teacher asks the student to revise the hypothesis about how the image will change, given what has happened so far in the experiment (Strategy 7). The student makes a conjecture, which is incorrect, but because the conjecture is well-reasoned, the teacher in line 95 is very encouraging. This was a strategy used frequently by the teachers who wanted to foster hypothesis formation by their students. In lines 95-99 the teacher has the student test his revised hypothesis (Strategy 6), and points out again that it was a good hypothesis, even though it turned out to be incorrect. This relates to Objective 3, "Predicting the effects of convex lenses on light rays."
11. In line 99 the teacher starts pursuing the subgoal of determining where the image flips over with respect to focal length. In line 100 the student appeals to authority (i.e., the teacher) to provide the correct answer, but in line 101 the teacher questions his own authority (Strategy 10) in order to encourage the student not to accept the answers given to them unquestioningly. This strategy is common among inquiry teachers who emphasize theory information in their teaching. This section relates to Objective 2, "Defining focal length."

12. In lines 101-114 the teacher gets the student to invent a procedure for measuring focal length of a lens. Then he has the student measure where the image turns over in terms of focal length. In both these efforts he is getting the student to learn how to test hypotheses (Strategy 6). In getting the student to invent a procedure for measuring focal length, the teacher is gradually turning over the thinking to the student so that he will learn to form and test hypotheses on his own. This section also relates to Objective 2.
13. Starting in line 115 and for the rest of the dialogue the teacher tries to get the student to draw representations for the various situations (or cases) that they established in the little mini-experiment. Again the teacher is using a strategy of systematically varying cases (Strategy 2), so that the student can see how the representations change from case to case. These drawings relate to both Objectives 3 and 4.
14. In line 116 the student makes a mistake in his drawing, by having the light rays bend more than they actually do, given the letter A is inside the focal point. In line 119 the teacher picks as a counterexample (Strategy 3) the previous picture they drew where the rays from the sun came in straight and bent together to the focal point. Then the teacher asks a series of questions through line 125 that

trace the consequences (Strategy 9) of the student's mistake in his drawing until he sees the contradiction (in line 126) with the way the rays bent in the previous drawing. Socrates was particularly fond of this consequence-tracing strategy, and it may be particularly useful in getting students to give up wrong hypotheses. This section is particularly aimed at Objective 3, though Objective 4 is also relevant.

15. In lines 129-143 the teacher tries to get the student to form a hypothesis (Strategy 5) from his drawing as to how two factors (curvature of the lens and distance from the object) affect magnification. He does this by introducing dotted lines that represent how the image appears, as opposed to how it is. This serves to introduce the notion of a virtual image. This is particularly relevant to Objective 4.
16. In lines 143-147 the teacher gets the student to represent the other two cases: (1) where the lens is midway between the paper and the eye and the image is upside down, and (2) where the lens is near the eye and the image appears right side up. Here the teacher is using systematic variation of cases (Strategy 2) in order to get the student to learn the rules for representing different configurations of eye and lens. This is particularly relevant to Objective 3.

The hypothetical student in the dialogue, while naive, is the best kind of student. The dialogue is perhaps a bit unrealistic in that the student leads the teacher on very few detours. These were avoided in order to present the basic goals, strategies, and control structure of inquiry teachers in a concise and coherent form. Even though real students are likely to be less intelligent and to lead dialogues astray much more often, I think the dialogue gives a good flavor of how the best inquiry teachers guide a discussion. They try to get students to analyze problems like scientists--to systematically consider different cases, to form and test hypotheses, to look for counterexamples. The kinds of experiments the teacher and student perform here together illustrate this well. It is a time-consuming way to teach, but if the goal is to teach students to solve problems or invent theories in a creative way, this may be the only method we have.

References

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Table 1

Different Instructional Techniques Described by Collins and Stevens (1983)

1. Selecting positive and negative exemplars (2, 7)
2. Varying cases systematically (3, 6, 7, 9, 13, 16)
3. Selecting counterexamples (6, 14)
4. Generating hypothetical cases (6)
5. Forming hypotheses (3, 4, 7, 9, 15)
6. Testing hypotheses (3, 8, 9, 10, 12)
7. Considering alternative predictions (4, 10)
8. Entrapping students (3, 6, 7)
9. Tracing consequences to a contradiction (14)
10. Questioning authority (11)

Note. Numbers in parentheses refer to the numbered comments in the text after the dialogue, where each strategy is discussed.



(a)

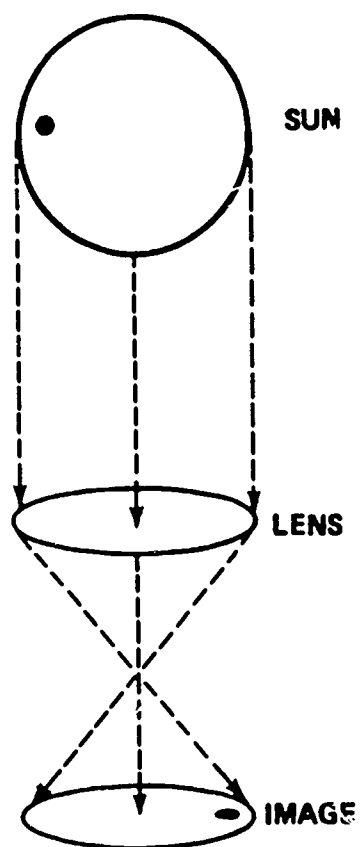


(b)

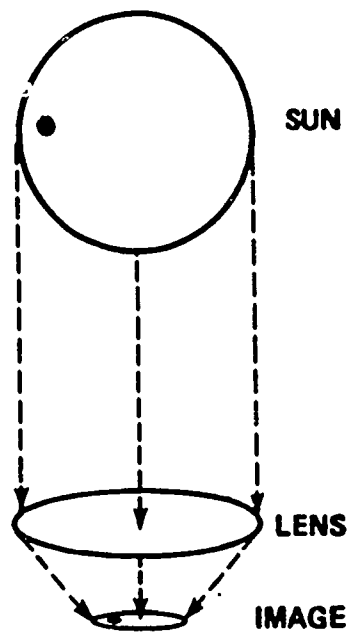


(c)

Figure 1. Three lenses for students to identify.



(a)



(b)

Figure 2. Two sketches by the teacher of the sun's image projected through a convex lens (the dot represents a sunspot).

**HEIGHT OF LENS BETWEEN EYE AND PRINT
(Width Indicates Magnification)**

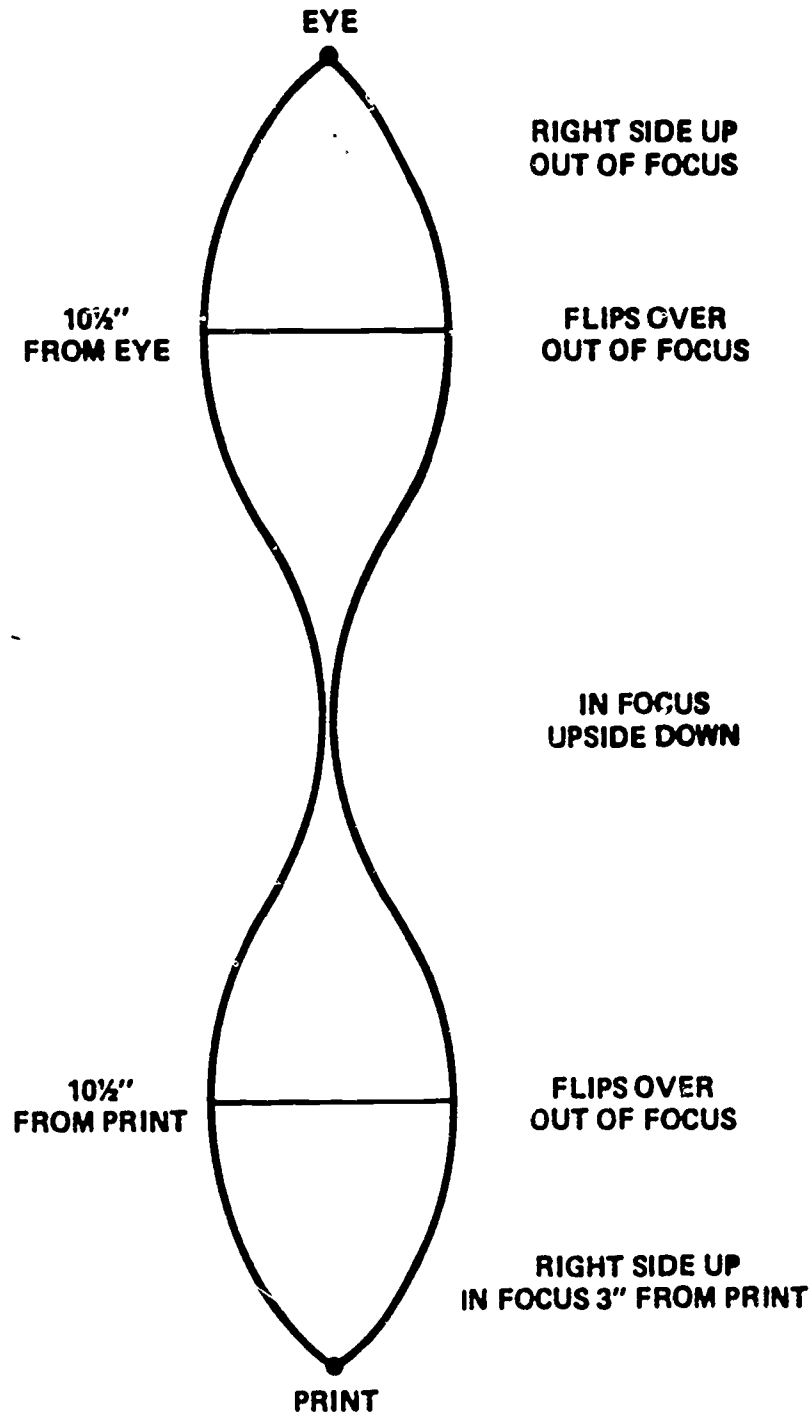


Figure 3. Schematic diagram of the results of the mini-experiment carried out by the teacher and student.

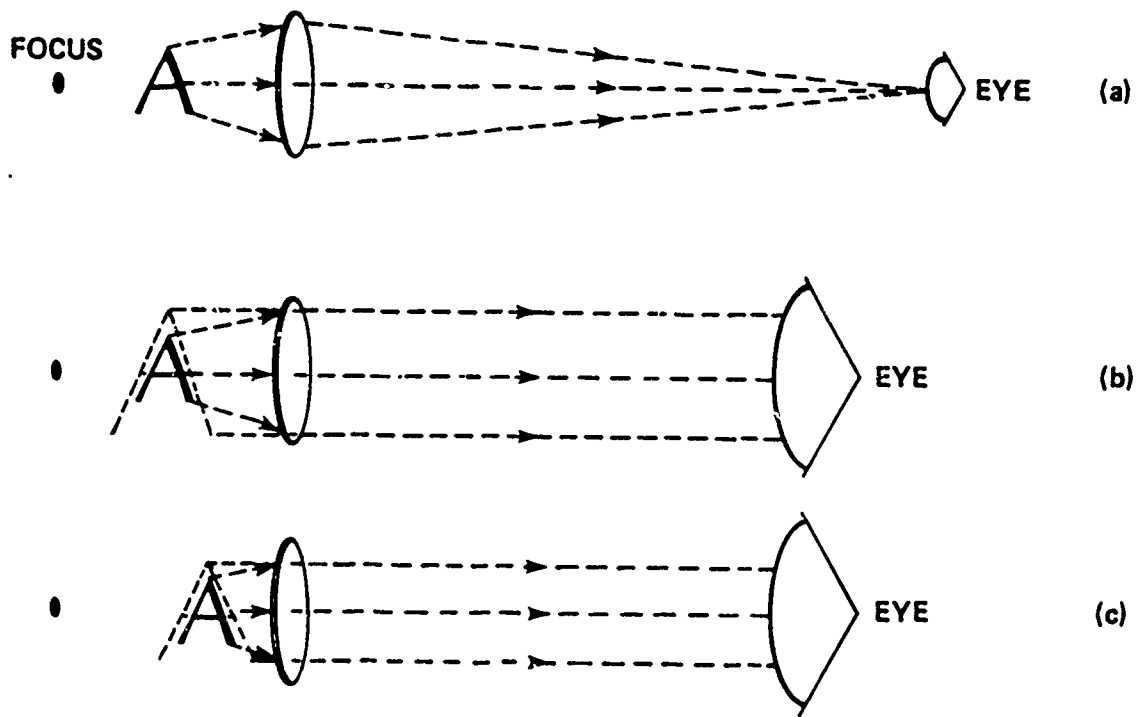


Figure 4. Three sketches by the student of how the light rays travel through a lens when the lens is held near the letter A.

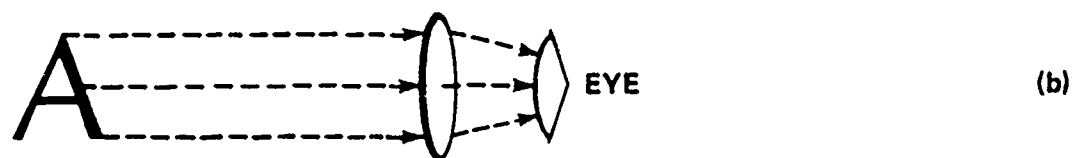
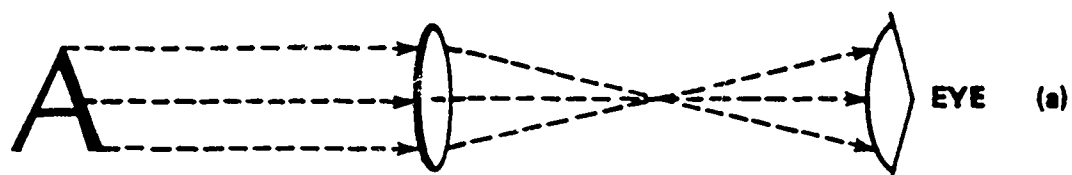


Figure 5. Two sketches by the student of how the light travels through a lens when the lens is held away from the print.